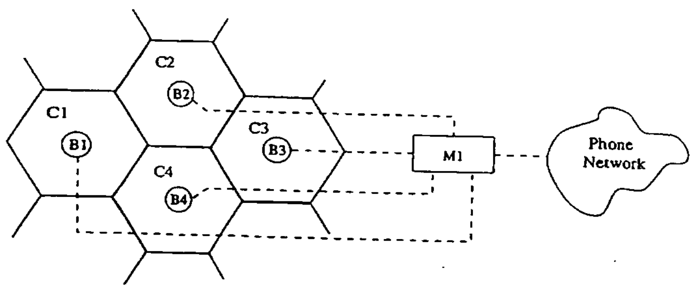
C1
B1
C2
B2
C3
B3
C4
B4
M1
Phone
Network

ABSTRACT OF THE DISCLOSURE

Apparatus for locating a mobile phone in a cellular phone system, in which the cellular phone system comprises plural base stations, each base station being associated with a cell, and in which the mobile phone is equipped with means for communicating signal strength of received signals to the base stations, has a processing unit operably connected to the plural base stations by first communications links, the processing unit having as input signal strength measurements of signals received by the mobile phone and having as output position location signals representing the position of the mobile phone in the cell, wherein, in operation, the processing unit operates upon the signal strength measurements to calculate a path loss exponent associated with the position of the mobile phone in the cell and solve for the position of the mobile phone using the path loss exponent. A user interface is operably connected to the processing unit by a second communication link for communicating the position of the mobile phone in the cell. Various algorithms may be used to solve the channel model equation. A method of locating a mobile phone by A) communicating signal strength measurements of signals received by the mobile phone to a processing unit; B) operating upon the signal strength measurements with the processing unit to calculate a path loss exponent associated with the position of the mobile phone in the cell; C) calculating the position of the mobile phone by using the path loss exponent as a factor in a channel model equation and solving the equation; and D) communicating the position of the mobile phone in the cell with a user interface.

A Cellular Telephone Location System

1 Inventors

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2 Field of the Invention

The field of this invention relates generally to wireless communications systems. More specifically, it relates to cellular telephone location.

3 Background of the Invention

Recently, there has been a great deal of interest in systems that determine the position of cellular telephones. In 1996, the Federal Communications Commission (FCC) in the United States passed a regulation requiring all cellular telephone service providers to provide Enhanced-911 (E911) service by 2001. E911 means that when a cellular phone is used to make an emergency call, the cellular system must be able to determine the physical location of that phone to an accuracy of 125 m, 67% of the time.

A great deal of work has been done in the cellular mobile location field. There have been many solutions proposed for the problem. However, most of these solutions require some modification of the cellular mobiles or base stations. Cellular networks are used extensively around the world. Cellular manufacturers and service providers have invested a great deal of money in the existing systems and standards. Any major modifications to these systems would require a great deal of effort and would cost a considerable amount. This means a solution that will function with the existing cellular systems is much more attractive.

There are several characteristics of a radio signal that can be used to determine the location of its source. Once characteristic is the strength of the signal. The average amplitude of a radio signal decays proportionally to the distance between the source of the signal and the point of reception. If the mobile were to monitor the strengths of known signals, transmitted from several known locations, those strength measurements could be used to determine the location of the phone. There are several patents that disclose location systems based on this principle.

P.W. Dent discloses his system in U.S. Patent 5404376. In this system, each base station transmits location information to the mobiles. This information consists of a table or contour of received strength of the signal from that base station vs. distance. The mobile measures the received signal strength from a base station and then uses the information it receives from that station to determine its distance from it. The mobiles also transmit back their signal strength measurements to the base stations who use them to update their contours. The disadvantage of this system is that it requires extensive modifications of the mobile and the base station.

Han-Lee Song discloses a different location system in U.S. patent 5208756. His system uses a location device placed in a vehicle that monitors the strengths of the signals received from the surrounding base stations. The strength of a radio signal decays proportionally to distance from the transmitter, according to an exponential factor. The system assumes that this path loss exponent and the transmit power for each base station is known before-hand from measurements or calculation. That information is stored in the memory of each location device. The device uses the log-distance channel equation to solve for the distances from the base stations to the mobile. It then uses the distances to triangulate the mobile's location. There are three disadvantages with this system. First, additional equipment or some modification of the mobile is required. Second, the

device uses the same equation to model all channels. Radio channels vary a great deal which makes characterizing them with a single equation very difficult. Finally, the path loss exponent for each base station can vary considerably, depending on location in the cell. Approximating this with a single value will result in errors in the system. Also, if there is any change in the path loss exponent values, the memory in every one of the location devices will have to be updated.

Unlike the first two systems, the system disclosed by D. Dufor in U.S. Patent 5613205 does not require the modification of the mobile. It uses signal strength measurements taken by the mobile that are used for another function. The system forces the mobile to sequentially go into handoff with each of its neighbouring cells. It then uses the signal measurements the mobile takes of the base stations as a result of the handoffs to determine the location of the phone. The distances from each of the base stations are calculated and the mobile position is found using triangulation. The disadvantage of this system is the added complexity of forcing the cellular phone to perform several unnecessary handoffs. This method could also cause degradation in call quality and would not work if the mobile had only a small number of nearby cells. It also increases the probability of a dropped call.

The system disclosed by J. R. Doner in U.S. Patent 5657487 also does not require modification of the mobile. It uses the signal strength readings the mobile takes of its surrounding base stations for Mobile Assisted Handoff (MAHO). It also uses transmission time advance information for each mobile to determine location. This system divides the cell into large contour regions based on signal strength measurements taken in the area. The MAHO measurements taken by the mobile are used to map it into a specific location using the contour regions. The location is further refined by constraining the position estimate to lie on known service areas, like roads. The disadvantage of this system is that it requires extensive signal strength measurements of the area to be made. Another disadvantage is that in order to constrain the position estimate to a known service area, the topolgy of each cell must be surveyed in detail and stored.

4 Summary of the Invention

The invention is a location system that uses signal strength measurements taken by a cellular mobile to determine the location of that mobile. In many cellular systems, the mobiles already measure the strength of signals received from surrounding base stations. This information can be used for operations like Mobile Assisted Handoff (MAHO). Since this feature is already incorporated into several digital cellular systems, the invention requires no modificiation of the mobiles or the base stations.

In order to determine the location of the mobile, the invention uses an appropriate equation model for the channel to express the signal strength measurements taken by the mobile as a function of the mobile's (x, y) position and the path loss exponent of the channel. There are several channel equations available that are suited for a specfic topology. The most appropriate equation is selected for each cell. The invention uses the signal strength measurements from the mobile in these equations to solve for the mobile's position and the path loss exponent of the channels. Several algorithms exist for solving these signal strength equations. If the algorithm needs a guess for the initial values of the position and path loss exponent, a prediction algorithm is used to determine accurate inital values based on the previous solutions of the signal strength equations.

The power of a signal in a radio channel decays exponentially with distance from the transmitter. The exponential factor in this decay is the path loss exponent. The path loss exponent is different for different channels and will vary, depending on the location of the mobile. By solving for the path loss exponent, the invention takes into account this variation between locations. This allows the invention to make accurate position estimates for a variety of different locations in the cellular system. The results are much better than if a single path loss exponent was assumed for the entire cell. This also makes detailed measurements of the cellular coverage area unnecessary. Only a brief survey of each cell is required to determine which channel model will produce the best results.

There are several improvements that can be made to the basic invention to enhance its performance. The invention could be modified to allow it to request measurements for a specific mobile from the cellular system. The effects of channel fading can be reduced by having the mobile take several readings from each base station over a small area. The readings are then averaged and the average is used in the signal strength equations. Also, assuming a single path loss exponent for all the channels between the mobile and the base stations can be inaccurate. To reduce this error, the base stations can be divided into groups and a path loss exponent value can be solved for each of the groups. The number of groups will depend on the number of measurements taken by the mobile.

There are also several improvements that can be made to the invention to help it cope with the problems presented by a practical cellular system. Directional antennas are often used to divide cells into regions called sectors. Using the radiation patterns and orientations of the antennas, the gain of these antennas can be determined by the invention and used in the signal strength equations. Also, a curve fitting algorithm could be used on the position estimates of the invention to find the mobile path that best

satisfies all the estimates. This would reduce the error in the estimated mobile path. Often, errors in the position estimate will be caused by only one or two base stations that have become obstructed. Solving for position several times, each time excluding different base station signal strength measurements, will help reduce the effect of the obstructed base station. Finally, there will be times when the algorithm attempting to solve the signal strength equations diverges and gives a very unreasonable solution. The prediction algorithm used to find the inital guesses for position and path loss exponent can be used to identify divergent solutions. If a solution is found to be divergent, it is discarded and not used. This same approach can be used to discard signal strength measurements that are obviously in error.

7 Brief Description of the Drawings

The invention is illustrated in the following drawings:

Figure 1 is a block diagram of a typical cellular system. Communication land lines are indicated by dotted lines.

Figure 2 is a block diagram of the first realization of the invention. The dotted lines indicate a communication land link between the connected blocks.

Figure 3 is a block diagram of the second realization of the invention. The thick dotted lines indicate a communication land link between the connected blocks.

5 Detailed Description of Preferred Embodiments

A typical cellular telephone system is shown in Figure 1. It consists of a large area divided into several smaller, contiguous areas called cells (regions C1 - C4). In theory, cells are considered to be hexagonal but in reality will be irregularly shaped. In each cell, there is a base station, B1 - B4, that communicates with all the cellular mobiles in its cell. Each base station is connected to the Mobile Switching Center (MSC), also called the Mobile Telephone Switching Office (MTSO), by a land communications link. The MSC is indicated by M1. The cellular traffic from each base station is directed to the MSC. The MSC serves to connect the cellular network to the main telephone network.

When a mobile leaves one cell and enters a neighbouring cell, a handoff occurs. A handoff means that as the mobile is making the transition from its current cell into a new cell, it stops communicating with the base station in the cell it is leaving and starts communicating with the base station in the new cell. Often, the mobile will assist in the handoff procedure. This is called Mobile Assisted Handoff (MAHO). Typically, the mobile will measure the strengths of the signals it is receiving from all the surrounding base stations. It then sends those measurements to its base station which can, in turn, forward them to the MSC. These measurements are used to determine if the mobile is making the transition into a new cell and is a candidate for handoff.

Equations for the signal strength measurements the mobile takes from each base station can be written using an appropriate channel model for each cell. The model that will give the most accurate results for the channel can vary, depending on the cell terrain. Some examples of channel models are the log-distance path loss model (T. S. Rappaport, *Wireless Communications, Principles and Practice*, Prentice Hall, 1996), Lee's Model (W. C. Y. Lee, *Mobile Communications Engineering*, McGraw-Hill, 1982) or Maciel's Model (L. R. Maciel, H. L. Bertoni and H. H. Xia, "Unified approach to prediction of propagation over buildings for all ranges of base station antenna height", *IEEE Trans. Veh. Technol.*, vol. 42, pp. 41-45, Feb. 1993). In general, these models predict the received power of a radio signal as a function of the distance between the transmitter and receiver and the path loss exponent. The received power of a radio signal will decay exponentially with distance. The exponential constant of this decay is called the path loss exponent. The value of this constant will depend on the condition of the channel. For a typical cellular system area, it could vary anywhere between the values of 2 and 4. There will also be some constants in each model equation that will depend on the antennas, the terrain, etc. .

The basic form of the invention is shown in Figure 2. The invention consists of a processing unit connected to the MSC by a digital communications link. As part of the cellular netowrk, the base stations are also connected to the MSC by communications links. Along with the other cellular traffic, the base stations return the signal strength measurements taken by each mobile to the MSC. These measurements are sent by the MSC to the processing unit over the communications link. If the signal strength mea-

surements are not returned by the base stations to the MSC, then the processing unit would be connected to each of the base stations by communication links, as shown in Figure 3. These links would be used to get the signal strength measurements from the base stations directly.

The processing unit uses the base station signal strength measurements taken by each mobile to determine the location of that mobile. After the measurements are received, equations for each of the base station measurements are formed. An equation is formed that is a function of the unknown distance between the base station and the mobile and the unknown path loss exponent of the channel. Since the position of each of the base stations is known, the distance becomes a function of the (x, y) position of the mobile. When forming an equation for the received signal strength measurement of a particular base station, the channel model equation that is most accurate for the terrain in the base station's cell is used. This means that different base station readings could have different equations. However, all equations will be functions of three unknowns: the mobile's x position, the mobile's y position and the path loss exponent. The terrain of each cell is examined beforehand to determine what channel model would produce the most accurate results for measurements of the base station in that cell. This information is stored in the processing unit.

Once the equations have been formed for the measurements taken by the mobile, the measurement values can be used in the equations to solve for the (x, y) position of the mobile and the path loss exponent. The values of the signal strength measurements are highly dependant on the path loss exponent. Its value will vary depending on the condition of the channel between the mobile and the base stations and the location of the mobile. Solving for the path loss exponent allows the invention to produce accurate results for a wide range of channels and locations. Once the mobile location and path loss exponent is solved for, it is either communicated to the user through a user interface or sent to another device using a communications link.

There are several algorithms capable of solving the signal strength equations for the location of the mobile. One example is Taylor-series estimation (W. H. Foy, "Position-Location Solutions by Taylor-Series Estimation", *IEEE Trans. Aerospace and Electronic Sys.*, vol. AES-12, pp. 187-93, March 1976). The invention will use the most robust technique for solving the signal strength equations for each particular set of equations. Depending on the different channel models used, the processing unit could use more than one technique for solving the equation sets.

Some of the algorithms for solving the signal strength equations require an initial guess as to the location of the mobile and the value of the path loss exponent. The algorithms will start at these values and iterate towards a final solution. When initial values are required, the invention uses a prediction algorithm to produce them. Based on the previous solution values for mobile position and the path loss exponent, the prediction algorithm will produce an estimate of what the current position and exponent values should be. The invention then uses those values as initial guesses for the algorithm that solves the channel equations. An example of a prediction algorithm that would

work is the Kalman filter but any appropriate prediction algorithm could be used by the invention.

A second method can also be used to find initial guess values for the location of the mobile. The mobile takes signal strength measurements from all the base stations around it. These base stations can be used to define an area. The invention can assume that the mobile will be in the approximate center of that area and use that point as an initial guess for the location of the mobile.

In some cellular systems, the mobile does not take a simple reading of the received signal power of the base station. Instead, the mobile returns a ratio. The numerator is the received signal power of the base station. The denominator can be the noise power received at that location. This type of measurement is called a signal-to-noise ratio (SNR) measurement. The denominator can also be the total power of all the signals the mobile is receiving. This type of measurement is called a signal-to-interference ratio (SIR) measurement. For both SNR and SIR measurements, the value of the denominator will be the same for all measurements taken at a single location.

If SNR or SIR measurements are taken, one technique the invention can use to solve for the mobile location and path loss exponent is the use of difference equations. Difference equations can be used to eliminate the unknown denominator in SIR or SNR measurements as follows. A reading from one base station is divided by the reading from another base station. Since the denominator values for each measurement are the same, they cancel and the result is the ratio of the received signal powers from the two base stations. When this result is expressed in dB, it is equal to the difference of the received base station signal powers, expressed in dB. The invention will then use the channel model equations for each cell to form an equation for this difference that is a function of the (x, y) position of the mobile and the path loss exponent. The mobile position and path loss exponent will then be solved from this set of equations.

The basic form of the invention has been described. The following example illustrates how the invention solves for the location of a mobile. In the example, SIR measurements are taken by the mobile. The log-distance path loss model is used to model all the channels between the mobile and the base stations. The Taylor-series estimation procedure is used to solve the equations. It should be pointed out that in a practical system, the invention would likely use different channel model equations to characterize the received signals from the base stations. A different algorithm for solving the channel equations could also be used.

The SIR from base station i can be expressed as

$$SIR_i = \frac{P_{r,i}}{P_{tot}} \tag{1}$$

where $P_{r,i}$ is the received power on the forward channel from base station i and P_{tot} is the total received power on the forward channel. The forward channel is the channel used by the base station to transmit information to the mobile.

The received power from base station i can be modelled using the log-distance model given in Equation 2.

$$P_{r,i} = P_{t,i} - \overline{PL}_i \tag{2}$$

The term $P_{t,i}$ is the transmitted power from base station i and $\overline{PL}_i$ is the average path loss of the channel. All terms are in dB.

The formula for average path loss in dB at some distance d_i from base station i is given in Equation 3.

$$\begin{aligned} \overline{PL}_i &= \overline{PL}_o + 10n\log\left(\frac{d_i}{d_o}\right) \\ &= \overline{PL}_o + 10n\log(d_i) - 10n\log(d_o) \end{aligned} \tag{3}$$

The term $\overline{PL}_o$ is the average path loss in dB at some reference distance d_o and n is the path loss exponent.

Combining Equations 2 and 3 with Equation 1, SIR_i in dB can be rewritten as

$$SIR_{i,dB} = P_{t,i} - \overline{PL}_o + 10n\log(d_o) - P_{tot} - 10n\log(d_i). \tag{4}$$

Difference equations are now used to eliminate the unknown denominator P_{tot}. They can also eliminate several other unknowns using the following simplifying assumptions. It can be assumed that the path loss $\overline{PL}_o$ at distance d_o and the path loss exponent n is the same for each of the forward channels between the mobile and the base stations. Assuming also that each base station is transmitting at the same power, the difference equations can be written as Equation 5.

$$SIR_{i,dB} - SIR_{j,dB} = 10n\log(d_j) - 10n\log(d_i) \tag{5}$$

The difference equation can be expressed as a function of the path loss exponent, the position of the mobile (x, y), the known position of base station i (x_i, y_i) and the known position of base station j (x_j, y_j).

$$SIR_{i,dB} - SIR_{j,dB} = 10\frac{n}{2}\log\left(\frac{(x-x_j)^2 + (y-y_j)^2}{(x-x_i)^2 + (y-y_i)^2}\right). \tag{6}$$

Since the positions of base station i and j are known, Equation 6 is a function $f(x, y, n)$ of the unknown (x, y) position of the mobile and the path loss exponent n.

The method used to solve for the three unknowns is Taylor-Series estimation. The method is based on approximating the function with the first two terms of the Taylor series. Equation 7 shows this approximation evaluated at the values x_o, y_o and n_o.

$$f_k + a_{k1}\delta_x + a_{k2}\delta_y + a_{k3}\delta_n = m_k - e_k \tag{7}$$

Where e_k is an error term and the other terms are defined as

$$\begin{aligned} f_k &= f(x_o, y_o, n_o) & a_{k1} &= \delta f_k/\delta x|_{x_o,y_o,n_o} \\ a_{k2} &= \delta f_k/\delta y|_{x_o,y_o,n_o} & a_{k3} &= \delta f_k/\delta n|_{x_o,y_o,n_o}. \end{aligned} \tag{8}$$

The term m_k is defined as the difference of the measured SIR from base station i and base station j. All possible difference equations are used, so the index k ranges from 1 to $N = C_2^t$ where t is the total number of SIR measurements taken by the mobile. The term C_2^t denotes the number of possible combinations of 2 base stations out of a total number of t base stations.

The system of equations for all of the measured values can be expressed in matrix form

$$\mathbf{A\Delta} = \mathbf{z} - \mathbf{e} \tag{9}$$

where

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ \vdots & \vdots & \vdots \\ a_{N1} & a_{N2} & a_{N3} \end{bmatrix} \quad \mathbf{\Delta} = \begin{bmatrix} \delta_x \\ \delta_y \\ \delta_n \end{bmatrix}$$
$$\mathbf{z} = \begin{bmatrix} m_1 - f_1 \\ m_2 - f_2 \\ \vdots \\ m_N - f_N \end{bmatrix} \quad \mathbf{e} = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_N \end{bmatrix} \tag{10}$$

Taylor-series estimation is an iterative method. For each iteration, the matrix $\mathbf{\Delta}$ is solved for using the least squares solution for an inconsistent system, shown in Equation 11.

$$\mathbf{\Delta} = [\mathbf{A}^{\mathbf{T}}\mathbf{A}]^{-1}\mathbf{A}^{\mathbf{T}}\mathbf{z} \tag{11}$$

Once $\mathbf{\Delta}$ has been solved for, δ_x is added to x_o, δ_y is added to y_o and δ_n is added to n_o. The iteration is repeated with $\mathbf{A}$ and $\mathbf{z}$ being recalculated with the new values of x_o, y_o and n_o. This process continues until the $\mathbf{\Delta}$ vector is essentially zero. At that point, x_o, y_o and n_o represent the best least squares solution to the taylor approximation of the signal strength measurement equations. The initial values for x_o, y_o and n_o are given by the prediction algorithm.

There are several enhancements to the basic form of the invention that will improve its operation. These improvements are listed below.

In the basic form of this invention, the processing unit is given the signal strength measurements for each mobile only as they become available from the mobile. One improvement would be to allow the invention to request signal strength measurements for a particular mobile from the MSC or the base stations. If necessary, the software in the mobiles, the MSC and the base stations would be changed to implement this.

One source of error for this invention is channel fading. Fading, when expressed in dB, can be modelled as an additive, zero mean Gaussian process on the received power of the signal. Channel fading can cause the measured signal strength to differ a great deal from the value predicted by the channel model equations. This difference can result in a large error in the mobile position predicted by the algorithm. In order to reduce

the effects of fading, the invention will average several signal readings of the same base station together. The measurements will all be taken by the mobile over a relatively small area. The average of the measurements will then be used in the channel equations.

In the example above, a single path loss exponent was assumed for all the channels between the mobile and the base stations. In some cases, the path loss exponent on some of the channels could be very different from the others. If this occurs, solving a single exponent value for all the channels will result in a large error in the position estimate. In order to reduce this error, the invention could divide the base stations into several groups. A path loss exponent could then be solved for for each group. The number of possible groups will be limited by the number of measurements available from the mobile.

In many cellular systems, directional antennas are used to divide the cells into sectors. This means that at a given location, the antenna gains of each of the surrounding base stations will be different due to different alignment and tilting of the antennas. However, by making use of radiation pattern measurements supplied by the antenna manufacturer and the known orientation of each antenna, the antenna gain pattern for each of the base stations can be determined. The invention can then use these patterns to determine more accurate antenna gains to be used in the channel equations.

Due to the hostile nature of the radio channel, there will always be some error in the position estimates calculated by the invention. In order to reduce error, the invention can employ a curve fitting algorithm that uses the calculated positions of the mobile as points on the curve. The curve fitting algorithm will find the path that best satisfies all the points. This will reduce the effect of a few position estimates with large error and give a more accurate estimate of the actual path of the mobile.

Errors in the position estimates of the invention can be due to one or two base stations having very different channels to the mobile than all the other stations. This might be due to an obstruction between the mobile and those base stations. The invention can overcome this by finding a solution for the position of the mobile several times, each time leaving out signal strength measurements from a different base station or group of base stations. The resulting measurements could then be processed to reduce the error due to the obstructed base station or group of base stations. For example, the average of all the solutions could be taken and used for the final answer.

The prediction algorithm used to find initial values for the algorithm that solves the signal strength equations can also be used to reduce the errors of the position estimates. Using the predicted velocity and position of the mobile, an approximate area is defined that should contain its next location. If the algorithm solving the signal strength equations diverges, giving a position estimate outside this area, the location estimate can be discarded and not used.

A prediction algorithm can also be used to discard signal strength measurements that are obviously in error. Prediction can be used to determine a reasonable estimate of what the next signal strength measurements should be. If the measurements disagree greatly with these estimates, they are discarded and not used in the signal strength equations.

6 Claims

We claim:

1. In a cellular communications system where the mobiles measure the signal strength of surrounding base stations, an apparatus for determining the locations of the cellular mobiles in that system. The apparatus consists of a processing unit that calculates the location of the mobile phones and the path loss exponent of the radio channels between each mobile and its surrounding base stations. The apparatus also consists of a user interface or communications link, connected to the processing unit, that is used to communicate the mobile positions and path loss exponents found by the processing unit. If the base station signal strength measurements taken by the mobiles are available from the MSC, the processing unit is connected to the MSC by a communications link. The communications link is used to send the signal strength measurements to the processing unit. If the measurements taken by the mobiles are only available from the base stations, the processing unit is connected to each of the base stations by a communications link. The communications links are used to send the measurements to the processing unit.

2. A method for surveying each of the cells in the cellular system, determining which channel model equation most accurately models that cell and storing that information in the processing unit of claim 1.

3. A method used by the processing unit of claim 1 to form equations for each of the base station signal strength measurements taken by a mobile. The equations are functions of the position of that mobile and path loss exponent of the channels. The equations are formed using the channel model equations found using the method of claim 2.

4. A method for the processing unit of claim 1 to use equations for SNR or SIR measurements to solve for mobile location and channel path loss exponent, if the mobile takes this type of measurement. An example of such a method is the use of difference equations. The difference equations are formed using the channel model equations found using the method of claim 2. They are a function of the position of the mobile and the path loss exponent of the channels and are equal to the difference between the signal strength measurements of two different base stations, when the measurements are expressed in dB.

5. A method for the processing unit of claim 1 to determine the most effective algorithm for solving the equations produced by the method in claim 3 or the method in claim 4 and to use that algorithm to solve for the position of the mobile and the path loss exponent of the channels.

6. A method for the processing unit of claim 1 to use a prediction algorithm to determine initial values of the mobile position and the path loss exponent value of the

channels, if the algorithm used in claim 5 requires them. The prediction algorithm will use the previous solutions of the algorithm used in claim 5 to determine the initial values.

7. A method for the processing unit of claim 1 to determine an intial value for mobile position, if the algorithm used in claim 5 requires it. The method consists of defining an area using the base stations measured by the mobile and using the center of that area as the inital value of the mobile position.

8. A method to allow the processing unit of claim 1 to request channel measurements, taken by a specific mobile, from the cellular network.

9. A method for the processing unit of claim 1 to average several signal strength measurements taken from each base station and use those averages in the equations produced by the method in claim 3 or the method in claim 4.

10. A method where the processing unit in claim 1 divides the base stations measured by a mobile into small groups and solves a path loss exponent value for each group.

11. A method where the processing unit of claim 1 uses a curve fitting algorithm on each of the positions solved for a specific mobile in order to determine a more accurate estimate of the path travelled by that mobile.

12. A method where the processing unit of claim 1 uses the antenna gain pattern of base station directional antennas to determine more accurate antenna gains to be used in the equations found by the method of claim 3 or the method of claim 4. The the method includes using the radiation pattern and orientation of each antenna to determine the antenna gain patterns.

13. A method where the processing unit of claim 1 is able to solve the equations produced by the method of claim 3 or the method of claim 4 several times. Each time, measurements from a different single base station or small group of base stations are excluded. The solutions are processed to reduce any errors that may be caused by a single base station or small group of base stations.

14. A method where the processing unit of claim 1 uses a prediction algorithm to identify solutions returned by the algorithm of claim 5 that have a large amount of error. Solutions that have a large amount of error are discarded and not used.

15. A method where the processing unit of claim 1 uses a prediction algorithm to identify base station signal strength measurements that have a large amount of error. Measurements that have a large amount of error are discarded and not used.

16. Apparatus for locating a mobile phone in a cellular phone system, in which the cellular phone system comprises plural base stations, each base station being associated with a cell, and in which the mobile phone is equipped with means for communicating signal strength of received signals to the base stations, the apparatus comprising:

a processing unit operably connected to the plural base stations by first communications links, the processing unit having as input signal strength measurements of signals received by the mobile phone and having as output position location signals representing the position of the mobile phone in the cell, wherein, in operation, the processing unit operates upon the signal strength measurements to calculate a path loss exponent associated with the position of the mobile phone in the cell and solve for the position of the mobile phone using the path loss exponent; and

a user interface operably connected to the processing unit by a second communication link for communicating the position of the mobile phone in the cell.

17. The apparatus of claim 16 in which the processing unit comprises a storage device in which is stored a channel model equation that models the cell.

18. A method for locating a mobile phone in a cellular phone system, in which the cellular phone system comprises plural base stations, each base station being associated with a cell, and in which the mobile phone is equipped with means for communicating signal strength measurements of received signals to the base stations, the method comprising the steps of:

A) communicating signal strength measurements of signals received by the mobile phone to a processing unit;

B) operating upon the signal strength measurements with the processing unit to calculate a path loss exponent associated with the position of the mobile phone in the cell;

C) calculating the position of the mobile phone by using the path loss exponent as a factor in a channel model equation and solving the equation; and

D) communicating the position of the mobile phone in the cell with a user interface.

19. The method of claim 18 further comprising:

surveying the cell;

finding a channel model equation that models the signal strength distribution in the cell; and

using the channel model equation in step C to calculate the position of the mobile phone.

20. The method of claims 18 or 19 in which the signal strength measurements are selected from the group consisting of SNR and SIR measurements.

21. The method of any of claims 18, 19 or 20 in which the channel model equation is solved by using difference equations.

22. The method of any of claims 18-21 in which a prediction algorithm is used to find initial values of the mobile position and path loss exponent for use in solving the channel model equation.

23. The method of any of claims 18-22 in which an initial value of the mobile position is used in solving the channel model equation.

24. The method of claim 22 or 23 in which the initial value of the mobile position is the center of an area defined by the base stations whose signal strengths are measured by the mobile.

25. The method of any of claims 18-24 in which the processing unit requests channel signal strength measurements from a specific mobile phone.

26. The method of any of claims 18-25 in which the signal strengths measured by the mobile phone are averages of several measurements made by the mobile phone.

27. The method of any of claims 18-26 in which a path loss exponent is calculated for a group of base stations.

28. The method of any of claims 18-27 in which several positions of the mobile phone are calculated and fitted to a curve to determine a more accurate estimate of the position of the mobile.

29. The method of any of claims 18-28 in which information on antenna gain patterns are used to solve the channel model equation.

30. The method of any of claims 18-29 in which the channel model equation is solved using signal strength measurements for more than one combination of the base stations for which signal strength measurements were taken.

31. The method of any of claims 18-30 further comprising predicting a solution to the channel model equation and discarding an actual solution that differs from the predicted solution by more than a pre-determined error.

32. The method of any of claims 18-31 further comprising predicting signal strength measurements and discarding signal strength measurements that differ from the predicted signal strength measurements by more than a pre-determined error.

33. The method of any of claims 18-32 in which the signal strength measurements are communicated to the processing unit through a mobile switching center.

34. The apparatus of claims 16 or 17 in which the first communication links comprise mobile switching centers.

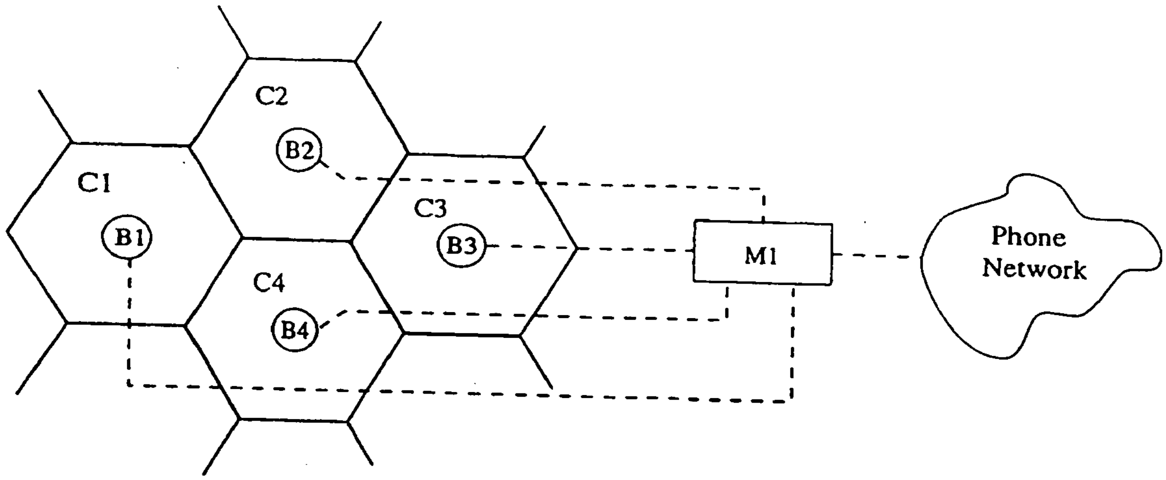

Figure 1

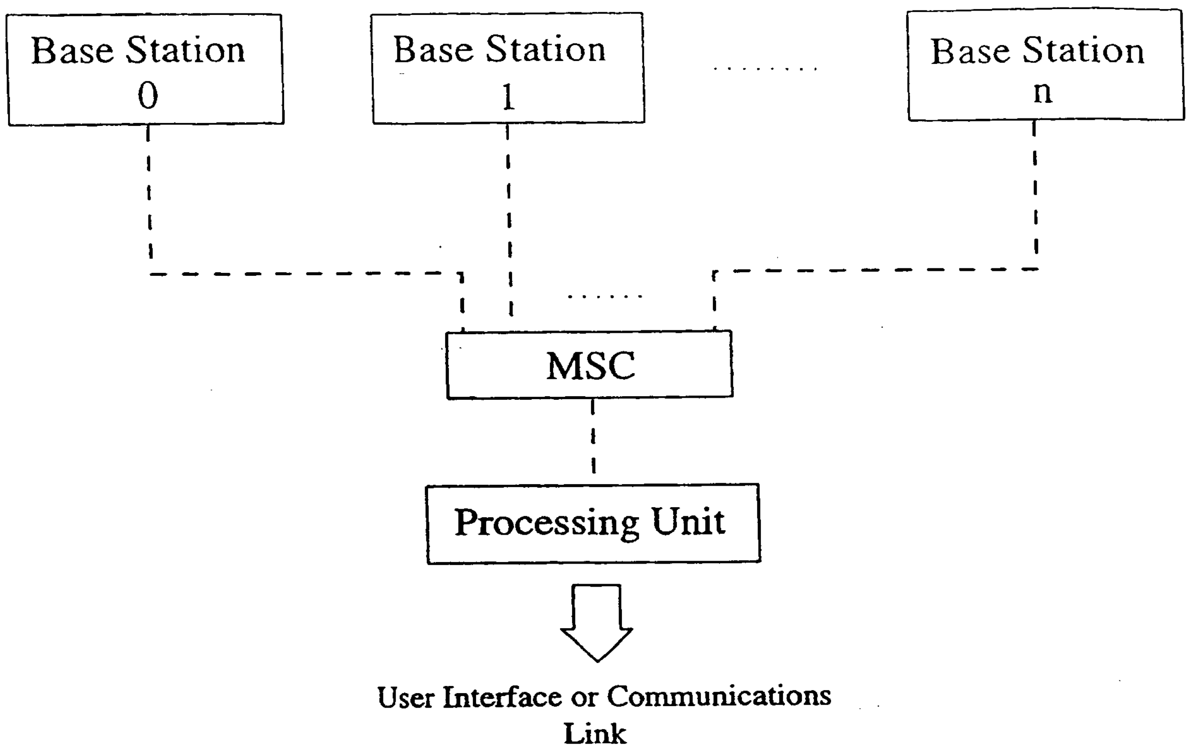
Base Station 0
Base Station 1
Base Station n
MSC
Processing Unit
User Interface or Communications Link

Figure 2

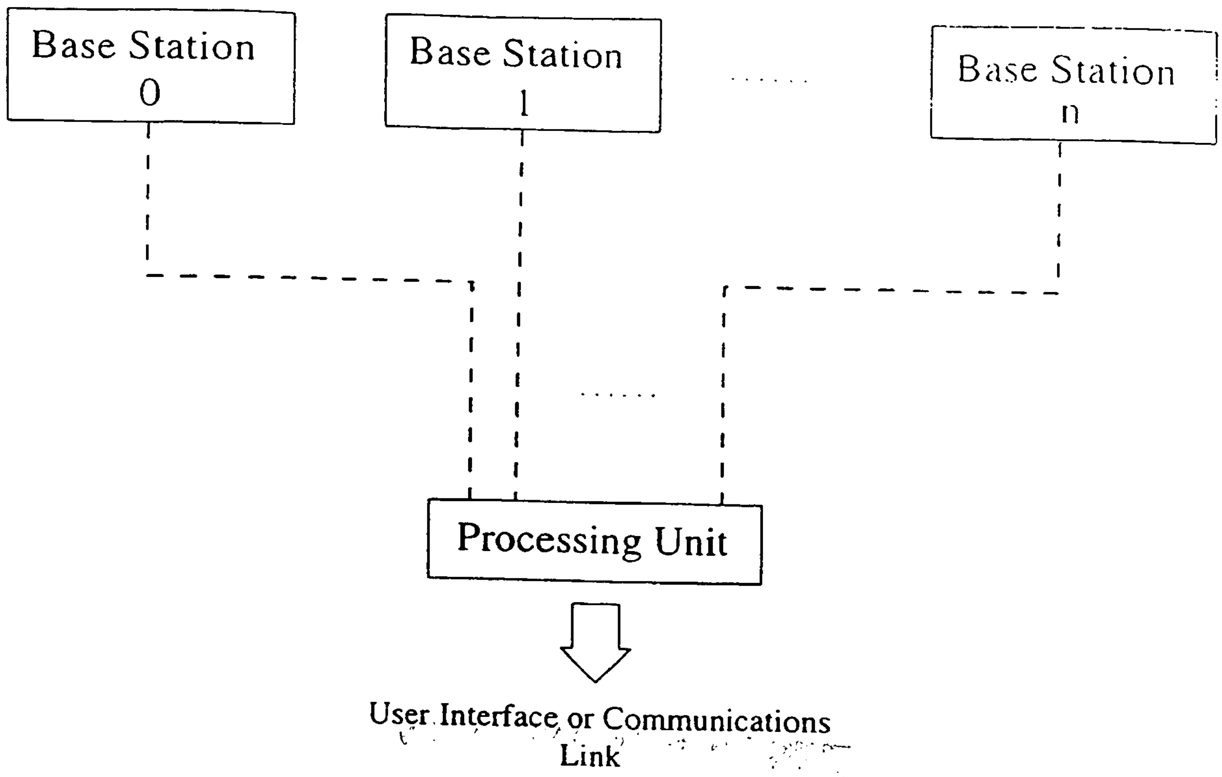
Base Station
0
Base Station
1
Base Station
n
Processing Unit
User Interface or Communications
Link

Figure 3